suspension and a decrease in the volume of stabilized water lowers it.

As the reaction is allowed to proceed only for a short while, the possibility of calcium ions disturbing the water lattice is low. Thus, the result of these measurements on the lime–water suspensions represents the influence of rate of interaction of the suspended lime with water on the viscosity of such suspensions.

When an accelerator ($CaCl_2$) is used along with normal Portland cement the deflexion, at a given rate of revolution, is reduced. This may occur because of loosening of the water structure by chlorine ions[1] and also by removal of calcium ions by the clinker crystals by adsorption. The latter may occur through capture of 'holes' by the adsorbed ions from the clinker minerals on the same line as the adsorption of lime from aqueous solutions by Fe_2O_3 (*p*-type reaction)[3]. Actual transfer may occur through (OH) groups associated with calcium ions. As the clinker minerals lose 'holes', the position of Fermi-level in these crystals is raised and their reactivity with water is enhanced[4] in the same manner as the acceleration of setting of Portland cement occurs when chrysotile asbestos is present[5]. Thus it appears that the acceleration of setting of cement (and the retardation, too) through chemical action may find explanation from the instantaneous position of the Fermi-level in the clinker minerals when these minerals react with water. Sucrose may retard the reaction between lime and water if the HO—C—H groups in sucrose get adsorbed on the lime surface through an 'acceptor' type reaction. Fermi-level is lowered and retardation of the reaction between lime and water becomes possible. Among the clinker minerals in Portland cement, as di- and tri-calcium silicate and tri-calcium aluminate, evidences are in favour of higher density of conduction electron in the latter two minerals[4]. With di-calcium silicate, then, the possibility of an 'acceptor' type reaction is less than with the other two minerals, and hence the cause of retardation of setting of cement by sucrose may possibly be both physical and chemical. Formation of a surface precipitate will mechanically hinder the reaction with water of di-calcium silicate, while the reactions with tri-calcium aluminate and silicate will be retarded by the chemisorption process on the same lines as in lime. This clarifies the views expressed regarding the mechanism of the action of sucrose as a retarder of the setting process in Portland cement[6]. Observed lowering of viscosity of cement suspension on addition of sucrose at low speeds can then be explained as due to both mechanical hindrance provided by the surface precipitates on di-calcium silicate and chemisorption on others. At higher speeds, precipitates (of sucrose) are thrown out, which goes into the solution and enhances the viscosity due to its own account[7] and also due to enhanced reaction rate.

For plaster of Paris, addition of an accelerator (K_2SO_4) increases the viscosity, while the effect of a retarder (boric acid) is to lower it. These facts may also be explained on the same principles, and on this basis the initial reaction between plaster of Paris and water should be considered as a solid–liquid reaction. This confirms the views of Hansen[8].

The results are thus explained on the assumption that the reaction between these materials and water is a chemisorption process. A chemisorbed layer of water is responsible for the stabilization of water lattice. The rheological property of the suspension will be governed by how far the absorbed layer of water is able to stabilize the water structure. Incidentally, an explanation of the action of accelerators and retarders on setting of cement has been given on the basis of chemisorption of the ions added. As these chemisorption processes are governed by the position of the Fermi-level in the suspended particle, the position of the Fermi-level in the solids is considered to be the factor controlling the rheological behaviour of dilute suspensions of materials which react with water by the chemisorption process, as well as controlling the acceleration and retardation of the setting process of cement.

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ENHANCEMENT OF LIGHT OUTPUT FROM A SUPERNOVA

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INTEREST has been aroused by the discovery that certain radio sources are associated with superluminous objects in distant galaxies. In particular, the source 3*C* 273 is 8–9 astronomical magnitudes brighter than a supernova explosion at the maximum of the light curve[1], and much of the emitted light appears to be synchrotron radiation[2]. Occasional flares occur in the light curve of this object, during which an excess energy of $\sim 2 \times 10^{46}$ ergs/sec is emitted within an interval of 10^5–10^6 sec[1].

Among suggestions which have recently been made to account for the large energy radiated by strong radio sources we may mention the following three:

(1) A chain reaction in a compact cluster of older stars in which one Type I supernova explosion triggers another[3].

(2) Collective formation of a cluster of more massive stars with similar evolutionary time-scales, which results in numerous Type II supernova explosions in a limited period of time[4].

(3) Formation of a very massive star (10^6–10^8 $M_\odot$), which implodes, releasing a substantial fraction of its rest-mass energy[5].

We have investigated a possible mechanism within the framework of the second of the above theories which may be able to account for the intense light flashes observed in 3*C* 273 (ref. 1). A normal Type II supernova explosion would not be visible against the strong light output from the 3*C* 273 object. However, the energy in one of the light flashes is the same order of magnitude as the expected kinetic energy in the ejected envelope from a star of 10–100 $M_\odot$ which undergoes a Type II supernova explosion. If occasionally circumstellar gas of density $\sim 10^{-16}$ g/cm^3 accumulates in a very compact cluster of massive stars, then the interaction of the shock-ejected stellar envelope with such a gas could convert much of the kinetic energy into visible light in the required period of time. The postulated gas density is much higher than normal interstellar gas densities, which assures us that this mechanism will have only a rare occurrence, but it would not be surprising to have such a density accumulate in a region such as that under discussion.

The short time-scale of the light flashes indicates that the energy must be released in a rather small volume of space. Solar flares are believed to result from the annihilation of magnetic field energy in the solar corona; they last for $\sim 10^3$ seconds. The annihilation time varies as the square of the dimensions of the annihilation region. The amount of energy released in a 3C 273 light flash is so many orders of magnitude greater than that in a solar flare, and the duration is so little greater that it is extremely unlikely that there is any similarity in the processes. It seems very unlikely that the light flash energy can be stored in space and released by any triggering mechanism; such storage would have to exceed 200 ergs/cm^3 in the volume that could be illuminated by a light pulse in 10^6 sec.

Our philosophy in selecting the most likely origin of the light flash has been to minimize the necessary energy content of the space within which the light flash is to be produced. The following crude analysis indicates that much of the kinetic energy of a shock-ejected supernova envelope (from a Type II explosion) can be converted into visible light if a significant fraction of the envelope is slowed by collision with circumstellar gases.

Massive stars are believed to undergo implosions, that initiate Type II supernova explosions, when nuclear evolution has converted their cores to iron, and the temperature has risen sufficiently to start the endothermic conversion of the iron to helium[6]. We have found that the implosion of the core continues until ordinary nuclear densities are somewhat exceeded[7,8]. In a recent theory by one of us[9], the deposition in the envelope of the energy of the neutrino flux from inverse β-decay in the collapsing core permits a fraction (~ 10 per cent) of the rest mass of the core to be converted into kinetic energy of expansion. The core is that fraction of the star that collapses adiabatically and in these calculations it has been ~ 20 per cent of the total mass. Thus a total energy release of several solar rest masses ($\sim 3 \times 10^{54}$ ergs) is predicted. The time of this release ($\sim 10^{-3}$–10^{-2} sec) is short enough so that a shock wave necessarily forms in the star external to the core.

Initially the shock wave will not be strong enough either to reverse the implosion of the matter or to eject it from the gravitational potential. However, as it proceeds outward it increases in strength both because of the density gradient and because of the additional neutrino energy deposition. At some point the shock becomes strong enough not only to reverse the imploding velocity but also to overcome the gravitational potential. The matter corresponding to this point asymptotically approaches final velocity after leaving the star, but the shock strength which accelerated it corresponded to the gravitational energy per gram at the time of shock passage. If nearly all the mass of the star is ejected, the mean energy of the shock becomes $\sim c^2/50$ erg/g. The corresponding mean ejection velocity for the bulk of the mass of the star would be $u_0 = 4 \times 10^9$ cm/sec. Consequently, only a two-fold increase in the strength of the shock as it proceeds in the density gradient of the envelope results in matter ejected with this velocity.

The increasing strength of such a shock as it proceeds in the envelope has been previously calculated in detail[10]. The resulting velocity distribution in the non-relativistic region can be approximated by:

$$u = u_0\left(\frac{10M}{M_0}\right)^{-1/5.5}, M \leqslant M_0/10 \quad (1)$$

where M is the integral mass external to the matter the velocity of which is u, and u_0 is the mean velocity of ejection (4×10^9 cm/sec for 100 solar masses).

If circumstellar gas of low density ρ surrounds the supernova, then half the incident shock energy $Mu^2/2$ will be converted into heat in a distance R, such that $M = 4\pi R^3\rho/3$, in a time $\tau = R/3u$ sec. The factor 3 in the denominator of the last expression makes allowance for the fact that most of the volume of the sphere is at a substantial fraction of R.

The heat deposited behind the shock may alternately be retained by the fluid or in the opposite limit may be completely radiated away. If the heat is retained, then in a spherically divergent flow the gas expands and the heat is converted into kinetic energy, leaving only a small fraction to be radiated away when the expansion causes the gas to become transparent. In the present problem we seek the opposite limit where the energy is radiated at the rate of deposition. Two conditions ensure this rapid radiation limit: (1) At thermal equilibrium, the radiation energy density Q is larger than the particle energy density. (2) The radiation mean free path (λ) is larger than the particle thermal relaxation length (l) behind the shock.

The last condition ensures that the thermal energy gradient at the shock front is at least as steep as Q/λ, and the first condition ensures that with this gradient the heat flow $Qc/4$ will be greater than the shock heating rate $Q(u_s - u_f)$, where u_s is the shock velocity and u_f is the fluid velocity behind the shock. For $u_s, u_f \ll c$:

$$\frac{u_s - u_f}{u_s} = \frac{\gamma - 1}{\gamma + 1} = (\text{compression})^{-1} \quad (2)$$

so that $Qc/4$ is always greater than the shock heating rate.

We shall assume that thermodynamic equilibrium prevails, and then examine this requirement to find the conditions that optimize the visible radiant energy flux.

If we assume a uniform density distribution and a mass equal to the incident mass, the total radiation rate becomes:

$$W_t = \frac{Mu^2/2}{\tau} = \frac{1\cdot 5Mu^3}{R} = 0\cdot 4m^{0\cdot 45}u_0{}^3M_0{}^{0\cdot 55} \text{ erg/sec} \quad (3)$$

which becomes as large as possible at the maximum ejected mass, $M = M_0/10$, giving:

$$W_{t\,\max} = 0\cdot 15\,\frac{M_0u_0{}^3}{R} \text{ erg/sec} \quad (4)$$

The maximum spectral fraction will be radiated in the visible when $3kT = h\nu = 5 \times 10^{-12}$ erg; or $T = 1$ eV.

The initial density ρ_0 corresponding to this radiation rate is determined by:

$$caT^4/4 = \rho_0 u^3/2$$

or:

$$\rho_0 = \frac{1\cdot 1 \times 10^{-4}T^4}{u_0{}^3} \quad (5)$$

The radius for equal mass at this density is determined by:

$$4\pi R^3\rho_0/3 = M_0/10 \quad (6)$$

giving:

$$W_{t\,\max} = 0\cdot 033u_0{}^2M_0{}^{2/3}T^{4/3} \text{ erg/sec} \quad (7)$$

Choosing $T = 1$ eV, $u_0 = 4 \times 10^9$ cm/sec, and $M_0 = 100\,M_\odot$ gives $W_t = 5 \times 10^{46}$ ergs/sec, mostly in the visible at a radius $R = 3 \times 10^{16}$ cm.

The assumption of equilibrium must be examined for these conditions.

In general, the ion slowing-down path-length due to dynamic friction with the shocked plasma electrons is small compared with the total gas thickness, provided the electron temperature is held below 5 keV by radiation. Since the relative ion energy is 8 MeV, this condition requires that the electrons radiate at least $10^3\ kT_e$. However, either the electron temperature must be in equilibrium with the radiation at a few eV, or low-energy (a few eV) bound–bound transitions must be available for non-equilibrium radiation as in the solar corona. For the latter case to be effective, the high atomic number species must not be completely stripped of bound electrons (three or more must remain bound). This latter condition for the carbon–nitrogen–oxygen group requires $T_e \leqslant 50$ eV, so that again radiation in the visible requires a relatively low electron temperature. One is forced to the conclusion that should the electron temperature rise above 100 eV behind the shock front, the visible radiation would become a small fraction of the total, and indeed the remaining radiation process, bremsstrahlung with Compton scattering, is small enough so that the electron temperature would run away to such a high value, $\gg 10$ keV, that the ion slowing-down length would become larger than the gas thickness, and no further shock would occur.

Therefore, we must demonstrate a self-consistent radiation loss rate large enough to maintain a low electron temperature at the heating rate of the shock (equation (5)).

The collisional shock thickness is determined by the dynamic friction between the electrons of the shocked plasma and the incident ions of the cold gas.

According to Spitzer[11], the energy loss time of a test charge of mass M and velocity u large compared with the thermal electron velocity of an ionized plasma becomes:

$$\tau_s = \frac{u^3 M^2}{(M/m) 8\pi e^4 n_e z^2 z_1^2 \ln \Lambda} \text{ sec} \tag{8}$$

For the low densities involved, $\ln \Lambda \simeq 20$, and taking $z = z_1 = 1$, the slowing-down length becomes:

$$L = \tau_s u = 5{\cdot}7 \times 10^{-17} u^4/n_e \text{ cm} \tag{9}$$

or:

$$L = 10^{-40} u^4/\rho_0 \text{ cm} \tag{10}$$

For the conditions of (6) and (7) this gives:

$$L/R = 4{\cdot}5 \times 10^{-3} \tag{11}$$

which confirms that there is a small fractional shock thickness, provided the radiation cooling is adequate.

The principal radiation loss from such a low-density plasma will occur due to the excitation of bound–bound transitions of the small fraction of high atomic number elements $z \geqslant 3$. If we assume an element composition similar to that of solar matter, then the CNO fraction, $f = 10^{-3}$, becomes the dominant radiation source. For transparent plasmas in the temperature range 5–50 eV, extensive studies of radiation loss from low-lying resonant transitions[12,13] show that the effects can be approximated by an effective allowed transition of 10 eV with a cross-section of 10^{-15} cm² for each atom. If the calculated radiation rate is then greater than the shock heating rate[7], the electron temperature will fall to a low enough value so that the radiation rate is limited to partial blackbody radiation with a larger fraction in the visible.

The energy radiation rate becomes:

$$W = (\text{volume})\, n_e n_i\, \overline{\sigma v_e}\, (h\nu) \text{ erg/sec} \tag{12}$$

With the assumption that nearly all the internal energy is radiated behind the shock, the shock compression would approach infinity. However, an upper limit is determined by the shock thickness, since a thinner layer would be subject to Taylor instability. The compression then becomes R/L and the 'transparent' radiation rate becomes:

$$W_R = 4\pi R^2 L f\, [6 \times 10^{23}\, (R/L)\, \rho_0]^2\, \overline{\sigma v}\, (h\nu) \text{ erg/sec} \tag{13}$$

Using condition (6), which maximizes the total available energy, and evaluating $\overline{\sigma v}$ for $5 \leqslant T_e \leqslant 50$ eV as 3×10^{-7} cm³/sec results in:

$$W_R = 2{\cdot}7 \times 10^{65} \frac{f M_0^3}{u^4 R^5} \text{ erg/sec} \tag{14}$$

Comparing this with the energy generation rate of the shock (equation (4)) shows that for radii less than the maximum $R_{\max}$ the resonant radiation can be greater than the shock rate. Therefore, the stability condition for a radiation-cooled shock can be met and the maximum radius becomes:

$$R_{\max} = 3{\cdot}7 \times 10^{16} f^{1/4} M_0^{1/2} u^{-7/4} \text{ cm}$$

which for $f = 10^{-3}$, $M_0 = 100\, M_\odot$, and $u = 4 \times 10^9$, gives $R_{\max} = 3{\cdot}7 \times 10^{16}$ cm and a radiation rate of 5×10^{46} ergs/sec.

At least 90 per cent of this radiation at the maximum radius will be in the ultra-violet, but at smaller radii the electron temperature will be reduced and a larger fraction will be in the visible. Consequently, it appears feasible to radiate an amount of energy from a shell interacting with circumstellar gas comparable with the amount measured by Smith and Hoffleit[1].

In addition, it can be noted that the thickness of the required circumstellar gas is small enough ($\leqslant 10$ g/cm²) so that the cosmic ray spectrum that may be produced by the shocked outer layers of the supernova[10] will be only slightly modified.

For general consistency, it is desirable to show that the model of a supernova explosion used here leads to the usual luminosity of a Type II supernova at the maximum of the light curve, if there is no circumstellar gas present. The absolute photographic luminosity of a Type II supernova at maximum is approximately -18 (ref. 14) corresponding to an energy emission in the photographic wavelength range of slightly less than 10^{43} ergs/sec. We may estimate the light emission from the expanding envelope in a very crude way by considering the decrease in temperature of the shock-heated envelope as it expands adiabatically, and by assuming that this temperature is also characteristic of the expanding envelope at optical depths near unity.

We have seen that the outermost layers of the pre-supernova are accelerated to near-relativistic velocities. Hence, after shock ejection, such layers will rapidly become optically thin while the temperature is very high. The bulk of the material is ejected at smaller velocities, and, as a result of the contraction of the inner parts of the pre-supernova, it will lie inside a radius $\sim 3 \times 10^9$ cm. This material will be heated by the shock wave to temperatures $\sim 4 \times 10^9$ °K (ref. 8). The energy density of radiation will then considerably exceed the thermal kinetic energy of the matter, and so the adiabatic expansion will be approximately characterized by a ratio of specific heats $\gamma = 4/3$.

Early in the expansion, $kT/3 \gg \langle h\nu \rangle_{pg}$, so that the luminosity $L \propto Tr^2$, where r is the radius of the envelope near optical depth unity. We have $T \propto (\text{density})^{1/3} \propto r^{-1}$. Hence $L \propto r$. Later in the expansion, when $kT/3 \leqslant \langle h\nu \rangle_{pg}$, L becomes a sensitive function of T; at the least $L \propto T^4 r^2 \propto r^{-2}$. Hence it is evident that the maximum light emission occurs when $T \approx 10^4$ °K. This will occur approximately for a radius $r \approx 3 \times 10^9\ (4 \times 10^9/10^4) = 1{\cdot}2 \times 10^{15}$ cm. Hence $L_{\max} \approx 4\pi r^2 \sigma T^4 \approx 10^{43}$ ergs/sec. There is great uncertainty in this figure, but it is in order-of-magnitude agreement with the observed luminosity.

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